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MEASUREMENT OF ELECTROMAGNETIC INTERFERENCE SHIELDING[1]

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ABSTRACT

This paper presents a review summary of radiated emission and interference shielding methodologies currently describes in brief on Electromagnetic interference measurement system allow measurement and reducing of electromagnetic interference by using electromagnetic interference shielding effectiveness. To use shielding technique as a coaxial holder with uniform diameters that maintains 50-ohm impedance throughout the length of the device. The EMI tester was calibrated and the shielding effectiveness of common and new materials was determined through several experiments.

Keywords: *EMI; Carbon nanofiber composite; coaxial test holder; electromagnetic interference; reinforced polymer; shielding effectiveness*

INTRODUCTION

Electromagnetic interference (EMI) can become a problem when emitted electromagnetic fields interfere with the operation of other electronic equipment. Electromagnetic fields are radiated from sources such as equipment for television, cellular telephone radio communication, computer, radar and other devices [1]. EMF could also take place due to distant sources such as radio transmitters, antennas and lighting which make incident electromagnetic fields similar to plan waves [2]. Common examples of EMI include disturbances in television reception, mobile communication equipment, medical, military and aircraft devices. In which interference could disturb or jam sensitive components, destroy electric circuits and promote explosions and accident. For example, there were five crashes of Blackhawk helicopters shortly after their introduction into service in the late 1980[3]. The cause of these accidents was found to be EMI in the electronics flight control system from very strong radar and radio transmission [4]. Furthermore, pilots have reported that their electronic devices show different reading that seems to be related to EMI generated by use of personal electronics in the airplane.

Given the rapid development in commercial, military, scientific electronic devices and communication instruments, there has been an increased in developing materials that could shield against electromagnetic radiation to prevent interference. The current material options that provide effective shielding effectiveness are metals, metal powder, metal-fiber filled plastic polyacrylonitrile (PAN) Nickel Coated Reinforced Polymers (NCRP), aluminum structures, coatings nickels and copper

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metalized fabrics and more recently, Nano-reinforced polymers composites[5] Typically limitation found with materials used for shielding to prevent EMI are associated with corrosion susceptibility, lengthy processing times, high equipment cost for production, difficulty of material utilization to build articles with complicated geometries, limited service life when using conductive layers due to peeling and wear and high reinforcement concentration. NCRP like carbon nanofiber, carbon nanotube and nanowire reinforced polymer metrics seem to overcome some of these limitations because they are lightweight materials with design flexibility, corrosion resistance and suitable for mass production through conventional plastic manufacturing technologies such as extrusion and injection molding.

Measuring Electromagnetic interference shielding effects at a broad frequency range for newly development materials is crucial to determine their properties and potential applications. Shielding effectiveness is defined for incident waves that are in transverse electromagnetic mode (TEM) i.e similar to plane waves caused by a distant source.

In a coaxial cable a transverse electromagnetic mode (TEM) is present. Meaning the magnetic and electric (E) field vectors are both perpendicular to the direction of current propagation [6]. New Nano engineered and Nano reinforced materials are relatively expensive, hence the specimen size required for testing its properties should be as small as possible. Currently there are numerous ways to conduct shielding effects testing that depends on the type of materials being used and their application [7]. Researchers can make use of several existing standards available to characterize to Shielding effectiveness (SE) of materials such as

- ASTM D4935-99
- ASTM ES7 – 83
- MIL-STD-188-125A,
- IEEE-STD-299-1991
- MIL STD -461C
- MIL-STD-462

It has been reported that using the ASTM D4935-99 standard coaxial holder to measure Shielding Effectiveness is convenient because of the relatively small specimens required for testing in comparison with military standards, which require 6 Cm Square sample [8] However because of their limited dynamic range and relatively large specimen dimensions, these standards may also be impractical and inadequate for testing some newly developed nano-reinforced materials. It is noticed that the ASTM - D4935-99 standard tester and the required specimen relatively large.

The ASTM D-4935-99 standard device has a complex shape and it is difficult to manufacture. It is a flanged circular coaxial transmission line, with internal shape that secures the sample and capacity couple the coaxial conductors. Measurement of insertion loss (IL) or SE using the ASTM – D – 4935-

99 standard tester could also be used to estimate the electronic conductivity and the near field – SE of electrically thin specimens [9]. The ASTM D 4935-99 standard presents several shortcomings that could generate different results among different labs, some to these differences may be associated with variations in the standard on some construction details, surface finish and dimensions at the ends of the tester where connectors or attenuator [9]. Some other details that have resulted in slightly different manufactured standard SE testers deal with the coating of the outer surface such as amount silver painting, uses and application type. SE Tester requires a disk with a diameter of 133mm which seems to be a small sample size when compared to other SE testing methods but in the case of NCRP materials like nanowires and newly synthesized Nanoparticles the cost to prepare such size specimens for initial characterization could be prohibitive for research in both academic and industry. Besides that, the mass of the ASTM – D4935-99 standard tester is about 18kg making it inconvenient for frequent handling during assembling and disassembling.

Due to such shortcoming of the ASTM-D4935-99 standard tester, there was a need for an accurate, economical and easy to manipulate tester that could address the current requirements for SE tester that could address the current requirements for SE testing. Similar issues have also been recently addressed by the other researcher such as Hong et al and Sarto et al (10) who designed new coaxial shielding effectiveness and their performance were compared to the standard ASTM D 4935- 99 tester. Their results are in agreement within the 50MHz - 1.5 GHz frequency range have shown that reducing the radius of the total flanged coaxial tester. Its working frequency range could be extended to higher frequencies up to 33.5 GHz.

An improved flanged coaxial EMI shielding tester with a relatively simple design was constructed and tested. It is a flanged coaxial tester with uniform diameters that maintain 50 Ω impedance throughout the length of the device. The Two ends of the tester were designed to directly attach 10dB, 50 Ω attenuators, with standard N-Type connectors, in Order to make it more practical and minimize the number of parts and connections in the entire shielding effectiveness testing setup.

The purpose of any shielding effectiveness (SE) test is to determine the insertion loss (IL) due to introducing a material between the source and signal analyzer. SE is determined by measuring the electric field strength levels with both reference E_R and Load E_L specimens this is without and with the shielding martial respectively

$$SE = 20\log_{10} (E_R/E_L) = (dB)_R-(dB)_L \qquad (1)$$

And it can also be determined by measuring power

$$SE = 10\log10(P_R/P_L) \qquad (2)$$

The SE coaxial tester impedance of 50 Ω throughout its length matches the impedance of the signal analyzer, cables, connectors and attenuators. This impedance was achieved by choosing the diameters “D” and “d” to compute the characteristic impedance, Z0 of a coaxial line

$$Z_0 = ({}^{\eta}_0 / 2\pi \sqrt{\varepsilon_r})in(D/d) \qquad (3)$$

Where ${}^{\eta}_0$ is free space wave impedance approximately equal to 377 Ω, D is the inner diameter of the outer conductor, “d” is the diameter of the inner conductor and ε_r is the real part of the relative permittivity of the dielectric material between conductors , which for air is equal to 1. Applying the previous equation to the coaxial holder and having air as the dielectric material, it is determined that the impedance of the holder is only a function of its dimension’s ‘D’ and ‘d’

$$Z_0 = 60in(D/d) \qquad (4)$$

The upper frequency limit for pure transverse electric mode (TEM) operation is the cutoff frequency f_c of the first higher order mode. Which can be computed using following equations

$$f_c = (n/ \pi) (2c /D+d) \qquad (5)$$

where n is appositive integer and equal to 1 for the principal mode and c is the speed of light equal to 3 x 10^8 m/s. Also, for the new SE tester the following dimensions were chosen to match the dimensions of female N – type connectors of 10 dB, 50 Ω attenuators

$$D = 7.32 \text{ mm}; \qquad d = 3.18 \text{ mm} \qquad (6)$$

Therefore, it was determined that the characteristic impedance of the tester is 50 Ω with a theoretical cutoff frequency of 18.2 GHz

According to the ASTM D 4935-99 standard, an electrically thin material must have a thickness tm less then .0.01 times the electrical wavelength, λ, of the signal transmitted through the specimen being tested. The electrical wavelength of the speed of light divided by the frequency of the signal. If a material is not electrically thin, measurements of shielding effectiveness (SE) should perform throughout the frequency range of interest. Electrically thin materials that are isotopic and whose electrical properties are independent of the frequency, might require SE measurements at only few frequencies since their EMI SE characteristics are independent of the frequency (10) Also it is known that the transition between near field and far field occurs at about the λ/(2π) from a dipole source. Table -1 shows the maximum thickness of a specimen to be considered electrically thin at the specified frequencies. Tests with coaxial SE testers are in the far – field region because the distance between the source and receiver is more than a quarter of the wavelength of the highest frequency used in the tests. If needed, near field SE can determined from far – field data for electrically thin materials [12] with the newly developed simple EMI SE tester, a specimen that is .165 mm thick or less will be considered a thin material at frequencies up to 18.2 GHz.

Sr. No.	Frequency f (10) GHz	Maximum thickness to be an electrically thin material, t_m (mm) mm	Wavelength λ (mm)	Near to far field transition (mm)
1	1	3.000	300.0	47.75
2	5	0.600	60.0	9.55

3	13.5	0.222	22.2	3.54
4	18.2	0.165	16.5	2.62

Table -1 Electrically Thin Material, Wavelength and near to far field transition

EMI SHIELDING EFFECTIVENESS DEVICE

The new electromagnetic interference Shielding Effectiveness device consists of two identical flanged parts that are clamped together to hold the outer part of testing specimen of two concentric rods that hold the circular central part of the reference specimen. The fanged conductors are attached using four nylon bolts. SE tester showing the 10dB attenuation attached to it. The flanged parts have threaded ends designed to couple standard N-type connectors, like the ones of the attenuators and cables.

Manufacturing of the tester was performed using alloy 360 brass rods. The manufacturing process of this new EMI Shielding Effectiveness tester was much simpler than the ASTM D-4935-99 standard device. Its dynamic range is much higher, it us lighter, less costly and easier to manipulate by the researcher Shielding effectiveness can be obtained from the transmission measurements of the load and the reference specimen and it equal the transmission of the reference (dB) minus the transmission of the load (dB) specimens, as indicated in (1). The reference and load specimens need to be of the same material and thickness. Therefore, it is imperative that Shielding Effectiveness testing be performed using both the reference and load specimens. Several reporters consider using air as the load specimens. Several reporters consider using air as the reference materials. However, doing so yields an insertion loss of 0 dB for reference; therefore, the SE of the sample is the negative of the transmission of the load specimen. As a consequence, this practice does not provide accurate results for absolute SE measurements.

Using newly developed SE tester, the transmission readings without material between the flanges. It can be observed that reading of – 20dB and 0 dB were obtained with and without attenuator, respectively, indicating good performance of the SE tester with an expected impedance match of 50 Ω. The results indicate proper operation up to ≈ 11 GHz, which closely corresponds to the expected resonance frequency for a radial transmission line mode in the space between the flanges. Consequently, the newly developed simple EMI – SE tester seems to perform satisfactorily up to 11 GHz.

A Commercial conductive gold film, AGHT-4, with thickness of 0.18 mm, with 4.5 Ohms/ Square surface resistively was used to calibrate the SE tester. In the case of a sample with thickness t, conductivity σ, complex permeability μ.

In the case of a single thin film alone with sheet resistance R_A, the thickness of the film and any supporting substrate is insignificant compared to the wavelength, t can be sent to zero and the equation is reduced as follows:

$$SE = - 20 \log10 [2 R_A\eta0 / 2R_A\eta0 +\eta^2 0](7)$$

In the case of gold film with a value of R_A equal to 4.5 Ω / square used for the calibration, a value of 32.6 dB SE is theatrically expected, computed by using equation (7). The EMI SE specifications of the AGHT-4 film according to the manufacturer. Therefore, acceptable EMI SE values were obtained with the new SE tester using an AGHT – 4 films for calibration. It should be noted that up to 1.5 GHz the SE value is 32 dB.

EXPERIMENT

Different samples were prepared to further elucidate the potential of the developed tester. The following list presents the materials that were prepared and tested to determine their EMI –SE

a) Low –density polyethylene (LDPE) sheet with thickness of 1.5mm
b) Mylar (PET) with thickness of 0.18mm
c) Aluminum foil with thickness of0.015mm
d) 15% weight VGVNF liquid crystal polymer (LCP) sheet with thickness of 1.25mm

In the case of the LDPE sample, pellets with a density of 948 Kg/ m3 and a melting temperature of 135 degree Centigrade were provided by Chevron Phillips Chemical Company. The pellets were hot pressed using a hydraulic press into sheets of 1.5 mm thickness. Commercial Mylar and aluminum foil were used with the provided thickness.

RESULTS

The shielding effectiveness of a low-density polyethylene (LDPE) heet (t = 1.5 mm). it can be observed that the reference reading in much lower than the – 20 dB attenuation generated by the two attenuators, which indicates that assuming 0 dB for the reference reading generates incorrect results. For example, assuming 0 dB for the reference reading. A SE of -30 dB would be reported, which is incorrect value because it is known that the SE of LDPE is ≈ 0 dB since it is transparent to electromagnetic interference. The electromagnetic Interference Shielding Effectiveness of aluminum foil resulted in about 40 dB An Aluminum plate was along tested but its SE was out of the operating range of VNA and measurement became meaningless. The reason for this is that the resistivity of aluminum plate is RA
= 2.85 x 10 -8 ohms / Square and yields a SE of 196 dB.

The Shielding Effectiveness of a Liquid Crystal Polymer (LCP) composite with a concentration of 15% weight of vapor grown carbon nanofibers (VGCNF). The thickness of the VGCNF / LCP was 1.25 mm and the SE obtained is close to 30 dB, indicating a performance similar to the aluminum foil. This nanotechnology material has good EMI Shielding Effectiveness properties which potentially make it suitable for EMI applications.

The transmission of the reference sample readings is critical when experimentally obtaining Shielding Effectiveness value, Reference sample reading for the materials tested. Reference sample readings have a strong dependence on thickness and conductivity. The non-conductive LDPE with a thickness of 1.5 mm has a smaller reference value as compared to non-conductive PET with a thickness of 0.18 mm. Likewise in the case of the aluminum plate which has smaller reference value when compared to aluminum foil. However, an exception occurs with the 15% weight nanofiber reinforced liquid Crystalline Polymer (LCP). This sample has a surface resistivity of 410 Ω/ Sq and a thickness of 1.25 mm. The surface resistivity of the AGHT -4 is 4.3 Ω/ Sq with a thickness of 0.17 mm. Given the thickness and resistivity value of the VGCNF/LCP sample, a lower reference value was expected, but VGCNF/LCP sample has a higher reference reading than the AGHT -4.
Only the air and aluminum foil have a reference reading of 0 dB. This observation summarizes the need to perform the reference sample test instead of assuming 0 dB for reference when measuring the SE of any materials. Several resonances effects are observed in the region of 2.2 GHz and 4.4 GHz which correspond to the total length of λ/2 and λ for the flanged tester measured from the interfaces with the N- type connectors. This indicates that there is an impedance discontinuity at the interfaces of the connectors, which needs to be compensated for the future designs.

Future work consists on researching the EMI –SE characteristics of numerous nano- reinforced materials and developing an understanding of the SE mechanism involved in nano – reinforced materials.

CONCLUSIONS

The design, constructions and testing results of simple flanged coaxial electromagnetic interference EMI shielding effectiveness tester was developed in this study. The tester was primarily designed to overcome several shortcomings of the ASTM D – 4935-99 standard tester, such as its relatively large sample dimensions, complexity of testing fixture and handling difficulty. Theoretically, the new tester could operate up to 18.2 GHz but it was experimentally tested up to 13.5 GHz, Measures of shielding Effectiveness with the newly developed simple EMI – SE tester were satisfactory to identify materials with potential use in electromagnetic interference or similar applications. This simple EMI – SE tester requires sample specimens with relatively small size, making it attractive in research applications where the testing material is expensive or difficult to obtain. Having developed, constructed, calibrated and tested a simple EMI – SE tester in this study will allow additional research in EMI SE characterization of new materials already available or currently being developed.

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